Characterization of Extrasolar Planets using SOFIA

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Astroph. June 2010
First part of this talk:

the landscape of extrasolar planets
why focus on transiting planets
some history, Spitzer results

Posters by Angerhausen & Krabbe
+ HIPO poster by Dunham et al.

Then:

Hot Jupiters: a problem in atmospheric structure
also hot super-Earths
What observations we need to make progress
What SOFIA can currently do
and comments on optimized instruments
Summary of the known exoplanets

Deming & Seager
review in Nature
462, 301 (2009)

Also, Seager & Deming
ARAA (2010), astro-ph/1005.4037

SOFIA in follow-up,
not discovery mode

Timing
• Radial Velocity
☆ Transit
△ Microlensing
x Direct Imaging
• Astrometry

Earth Masses

Semi-Major Axis (AU)
Exploit *transits* to characterize exoplanet atmospheres...

Transits require photometric stability

But tolerate poor image quality

few $x \ 10^{-3}$ FLITECAM & FORCAST(?)

- 1 to 3 hours

Measure size of transiting planet, see radiation from star transmitted through the planet's atmosphere

Gravitational tug of unseen planets alters transit times

few $x \ 10^{-4}$ HIPO + FLITECAM
Methane and water vapor in transmission (HD189733b)

Arguably, SOFIA continuous viewing is a good tradeoff for some telluric water...

Charbonneau, Brown, Collier-Cameron, Deming, Richardson, Wiedemann, and others struggled towards ground-based detection.
"First Light"
Thermal Emission

Spitzer enables direct detection of IR light from the planets.

eclipse depth \( \sim (R_p/R_{\text{star}})^2(T_p/T_{\text{star}}) \)

yields \( T \sim 1100K \)

**Six Spitzer photometric bands can give a low resolution spectrum of the planet**
Eclipse of HD 189733B

eclipse depth \sim (R_p/R_{\text{star}})^2(T_p/T_{\text{star}})

\textbf{Dominant term}

T_p \sim T_{\text{star}} \Delta^{0.5}

\textit{lower main-sequence stars allow high S/N planet detection}

HD 189733b (K3V)

\textbf{32\sigma detection at 16 \mu m}

An Exoplanet Spectrum (R ~ 100)

HD189733b
(At Secondary Eclipse)

Grillmair et al. (2008)

Deming et al. (2006)
Charbonneau et al. (2008)

\[ P_n = 0.1, \kappa_e = 0.0 \text{ cm}^2/\text{g} \]
\[ P_a = 0.3, \kappa_e = 0.0 \text{ cm}^2/\text{g} \]

Many other planets show inverted atmospheric structure
The MEarth Project
Charbonneau et al.

- Using 8 X 16-inch telescopes to survey the 2000 nearest M-dwarfs for rocky planets in their habitable zones
- Converted an existing abandoned building on Mt Hopkins, AZ
- Fully operational; southern version planned
- These planets will be amenable to spectroscopic follow-up to search for atmospheric biomarkers
The First MEarth Super-Earth

Nearby, hotter super-Earths to come
TrEs-4 – apparently an inverted atmosphere

But there are degeneracies...

Warm Spitzer has only 2 bands

The very hot Jupiters atmospheres perturbed by strong irradiation? losing mass by tidal stripping?

WASP-12

CoRoT-2

High S/N for WASP-12 at filter resolution

Instrument considerations:
- maximize the spectral range
- $R \sim 100$ is OK
- maximize stability
- consider $\lambda$-dithering

hot super-Earths?
Conclusions and comments

- SOFIA with current instruments can make significant progress on the science of transiting exoplanets
  - Mass loss and atmospheric structure of very hot Jupiters
  - Complementary to Warm Spitzer
  - Possibly can characterize hot M-dwarf super-Earths

- Instrument enhancements should concentrate on stable 1-5 μm spectroscopy, maximizing the spectral range at relatively low spectral resolution